

A Python Data Analysis & Synthesis Toolbox for PSWS Doppler data: Time-of flight Case Study

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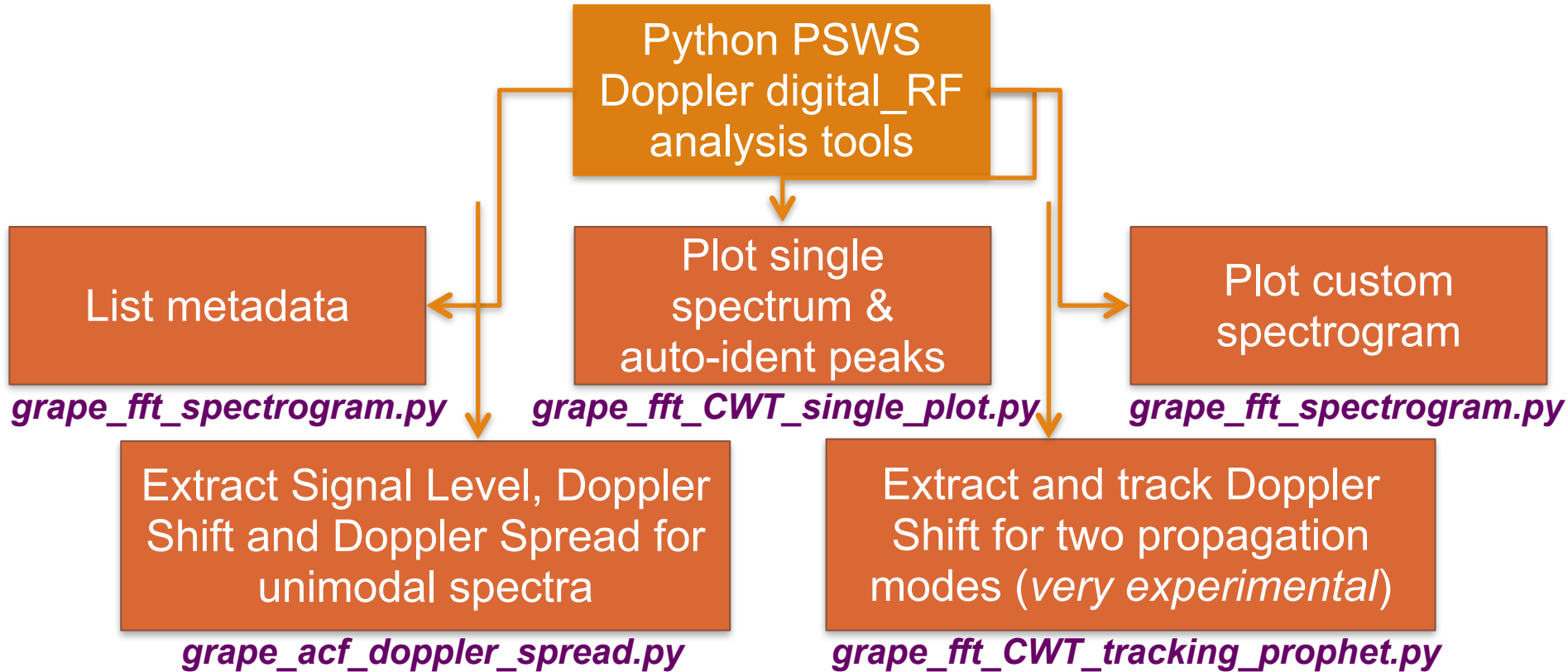
Member, Radio Society of Great Britain Propagation Studies Committee

with Time of Flight data from

**Scott Newell N5TNL, Paul Elliott WB6CXC, Clint Turner KA7OEI, Bret Anderson KG7RDR,
Michael Hauan AC0G and Rob Robinett AI6VN**

Acknowledgement: The ionosonde data was released under CC-BY-NC-SA 4.0 with acknowledgement to Lowell GIRO Data Center and the Idaho National Laboratory. PyLap (a wrapper for PHaRLAP, created by Dr Manuel Cervera, Defence Science and Technology Group, Australia that incorporates the International Reference Ionosphere /dat/iri2016/00_iri2012-License.txt) was made available via HamSCI. The HamSCI PSWS project is led by the University of Scranton in collaboration with Case Western Reserve University, the University of Alabama, and the New Jersey Institute of Technology. Funding is provided by National Science Foundation Grants AGS-2230345, AGS-2230346, AGS-2432821, AGS-2432822, AGS-2432824, AGS-2432823 and NASA Grant 80NSSC23K1322.

Data Analysis Tools



Data *Synthesis* Tools Great Circle Path

5 minute time interval

Automatic Script for
2D PyLap Ray
Tracing

0.005° elevation interval

Find all rays within
2 km of receiver

Assign propagation
mode 1E, 2F etc.

synthspec.py

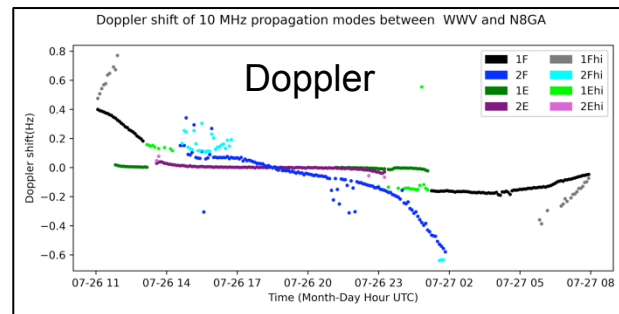
Synthesize
parameter time
series

pathfinder.py and pathfinder.sh

modefinder.py

Synthesized time series *by propagation mode* of:

- Ray elevation
- Ray apogee height
- Doppler shift
- Time of Flight



Data *Synthesis* Tools Two-Hop Sidescatter

10 or 20 minute time interval

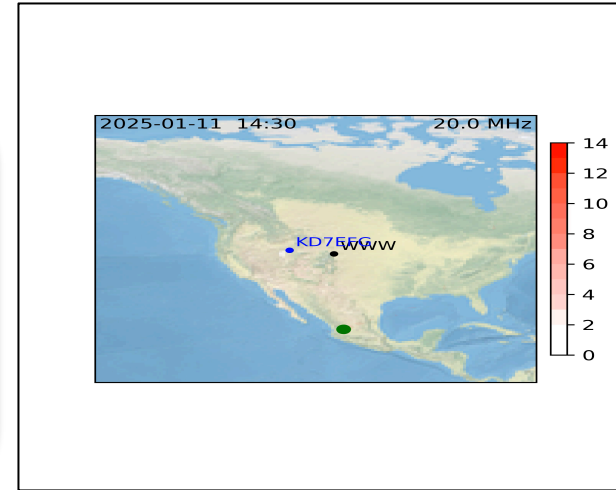
Automatic Script for
3D PyLap Ray
Tracing

1° elevation interval
3° azimuth interval*

Find all
one-hop
ray landing
spots from
Tx and Rx

Calculate
and plot
sidescatter
likelihood
metric

Animate

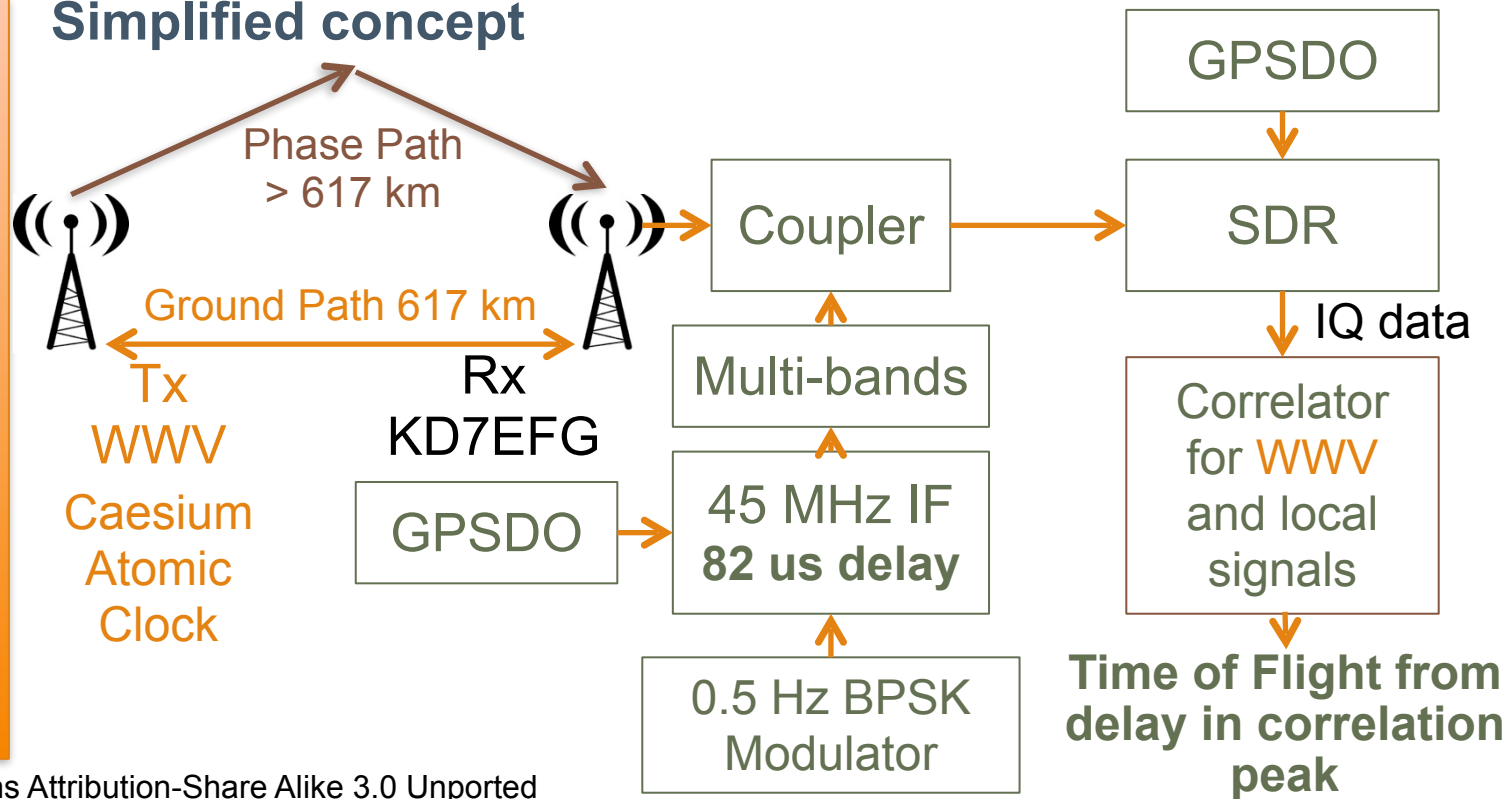


SS_sidescatter.py *SS_sidescatter_plot.py* *SS_animate.sh*

Case Study: Time of Flight WWV to KD7EFG N. Utah

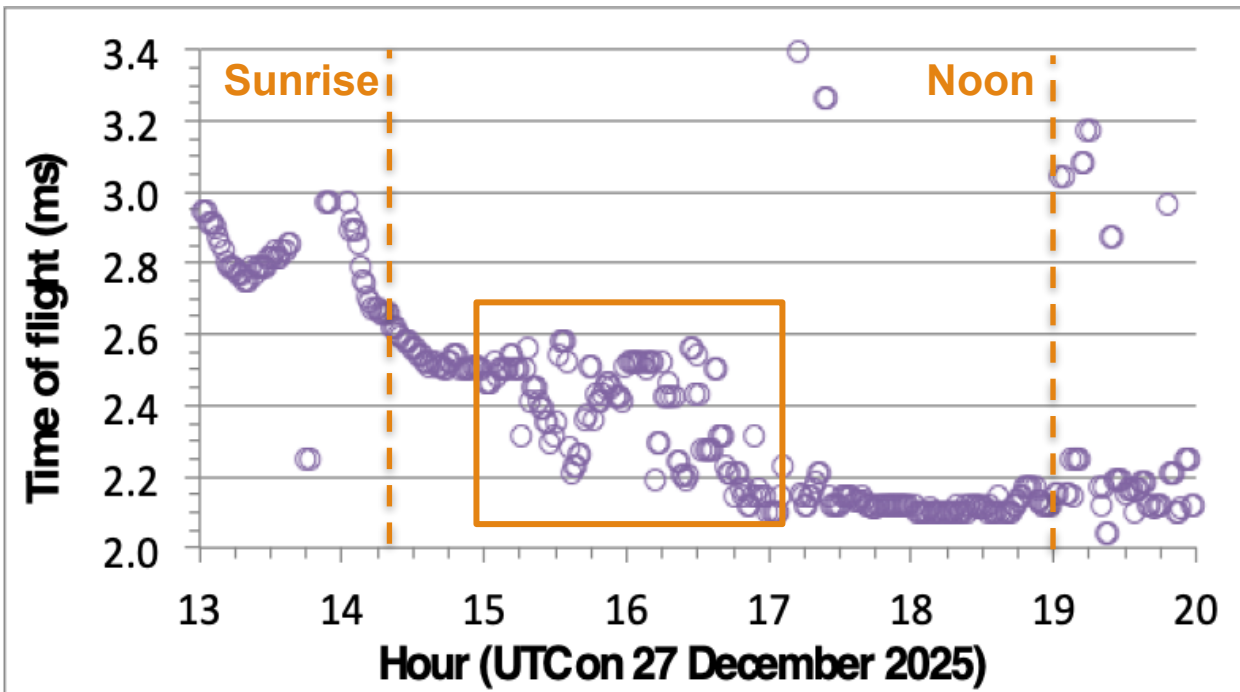
Reminder: The Time of Flight data is the product of much work and ingenuity in hardware and software of Scott Newell N5TNL, Paul Elliott WB6CXC, Clint Turner KA7OEI, Bret Anderson KG7RDR, Michael Hauan AC0G and Rob Robinett AI6VN.

Simplified concept



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WWV to KD7EFG 617 km path on 5 MHz 27 December 2025

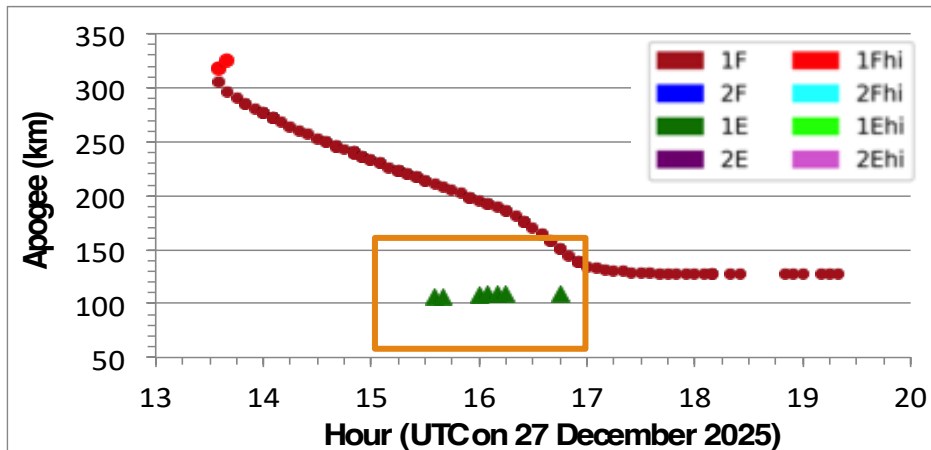


Time of Flight every one minute after:

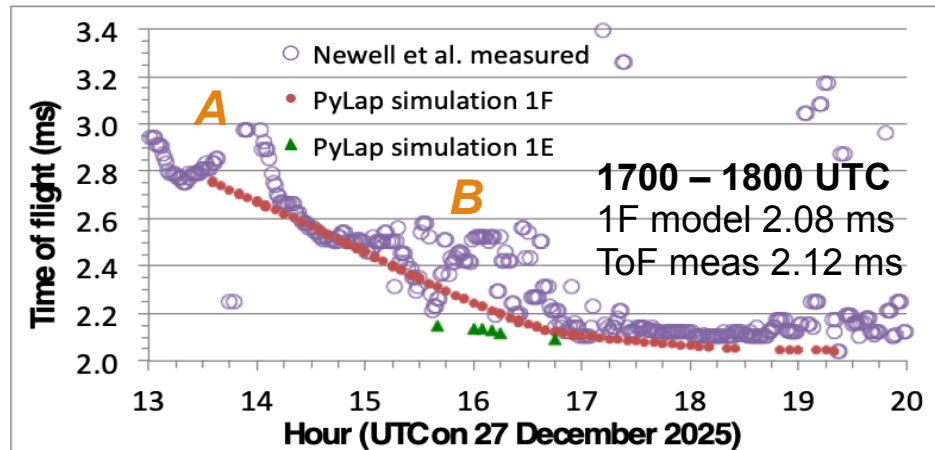
- Parabolic interpolation of raw 62.5 us time resolution data
- Correction for 82.2 us local time signal delay
- 5-point running median filter

Sunrise and sunset at path mid point.

WWV to KD7EFG 617 km path on 5 MHz 27 December 2025

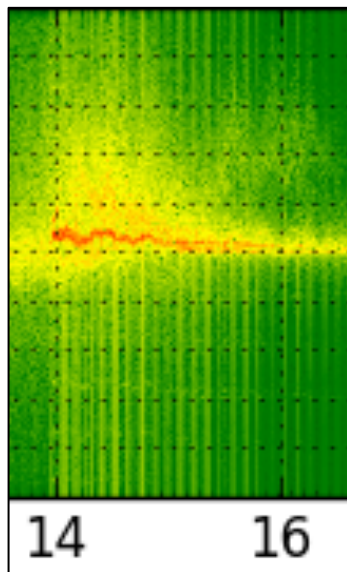


- Toolbox scripts *pathfinder.py* then *modelfinder.py* produce time series of apogee heights, and *synthespec.py* ToF.
- In this interval only one-hop F (1F), one-hop F higher elevation (1Fhi) and one-hop E (1E) appear.

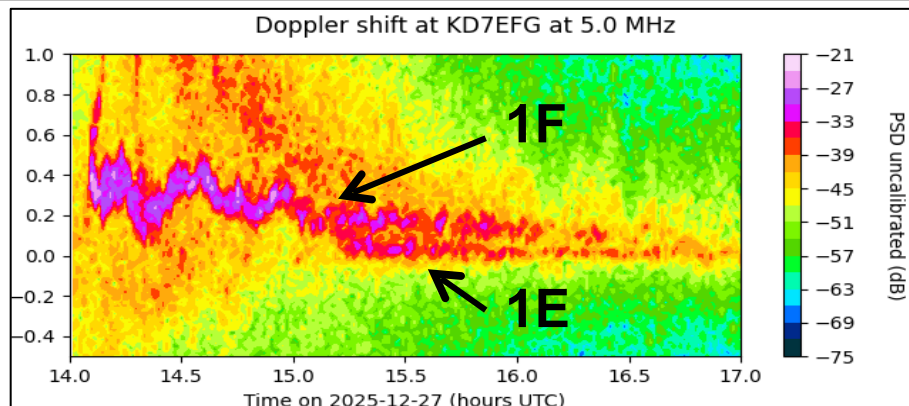


- 5 MHz opened earlier than in PyLap International Reference Ionosphere
- Variations at **A**: likely Travelling Ionospheric Disturbance, not in model
- Variations at **B**: ToF algorithm affected by co-propagating 1F and 1E modes.

Co-propagating 1F and 1E modes on 5 MHz

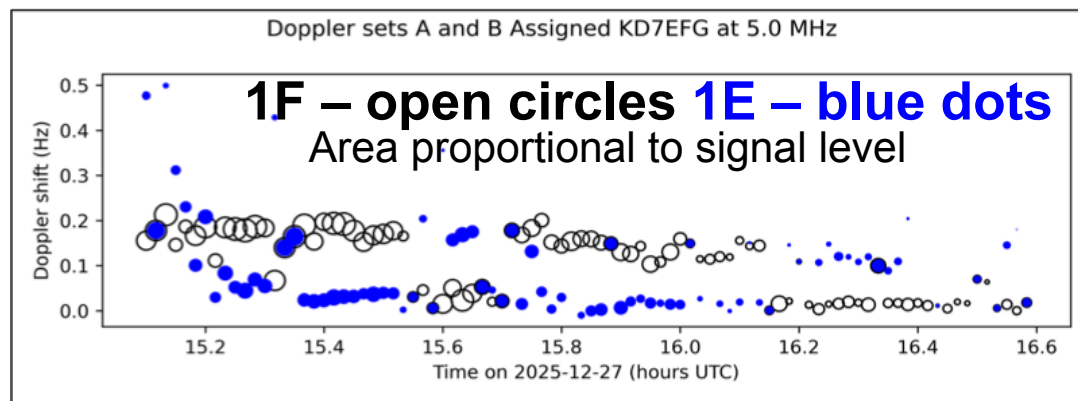


The otherwise excellent online spectrograms little use here.



grape_fft_spectrogram.py

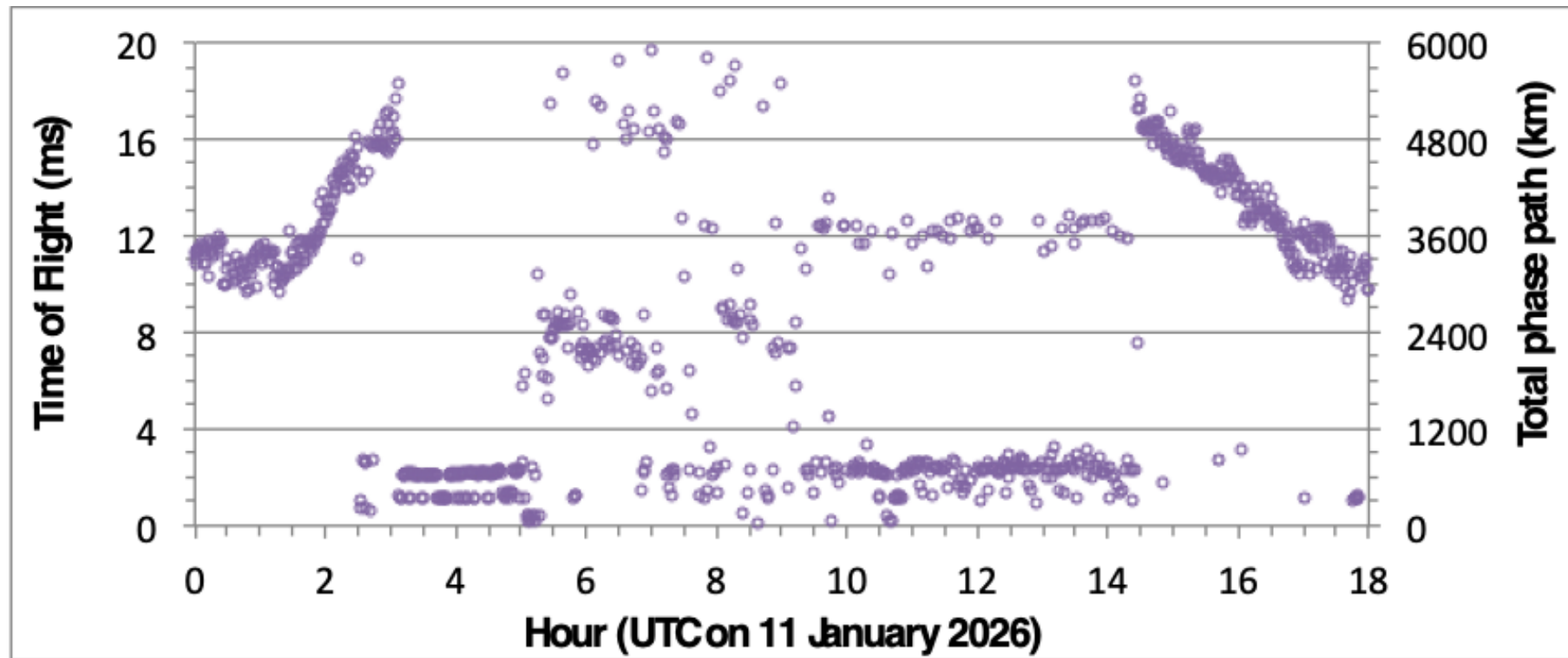
User-selectable time and Doppler spans allow us to zoom in and see the co-propagating E and F traces.



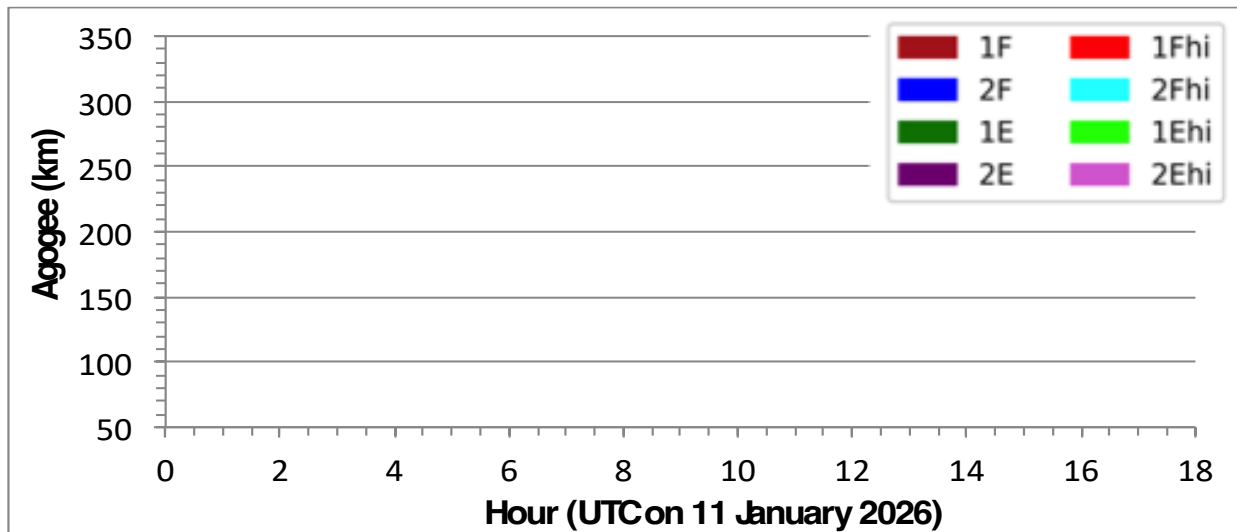
grape_fft_CWT_tracking_prophet.py

Certainly *finds* the Doppler shift of the two modes but *has trouble* classifying to **1F** and **1E**.

WWV to KD7EFG Time of Flight on 20 MHz 11 January 2026

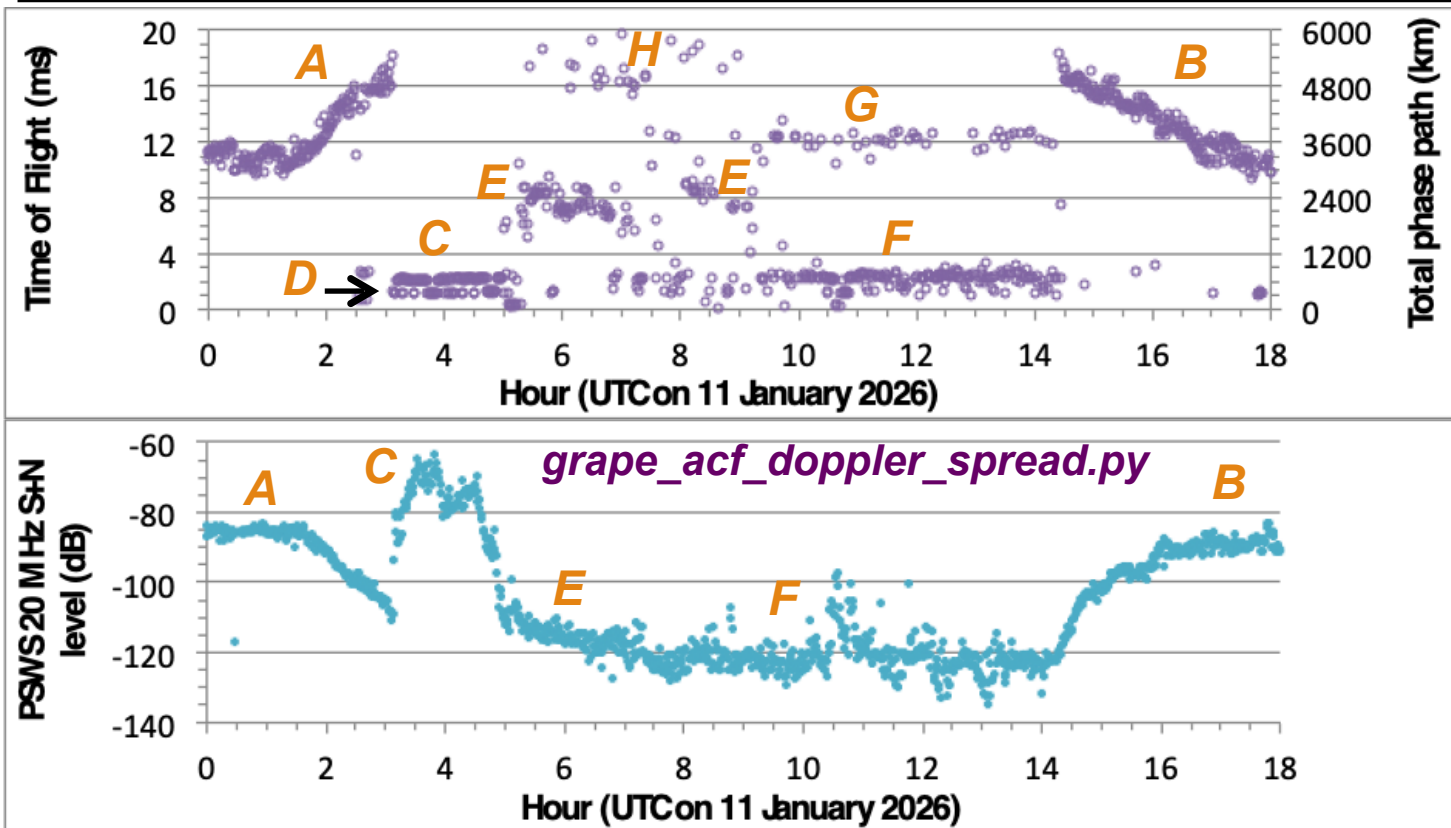


PyLap / IRI ray traces for 20 MHz 11 January 2026



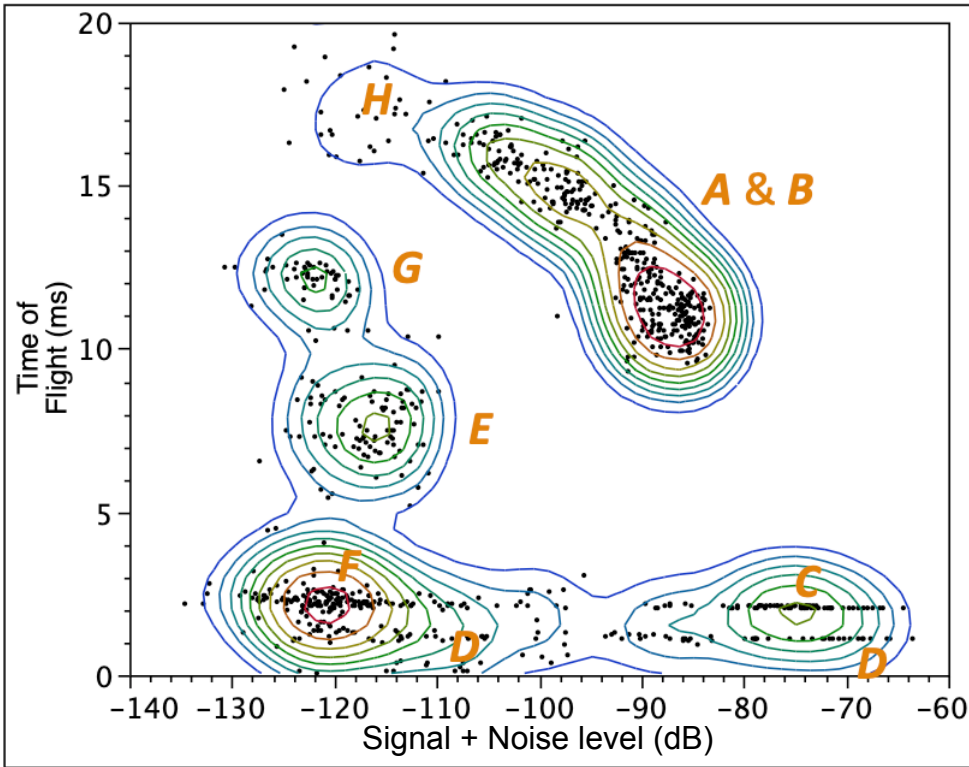
- ❑ No propagation paths along the 617 km great circle path were open in PyLap's International Reference Ionosphere
- ❑ KD7EFG was well and truly within the skip zone from WWV
- ❑ And so to the puzzle: *What were the several types of modes producing ToF data?*

Time of Flight and WSPRDaemon Grape Signal+Noise Level



Some ToF clusters seem to be associated with distinct signal+noise levels or patterns. ToF data labelled **D**, at <2 ms, are signal processing artefacts.

Cluster analysis of ToF and S+N level

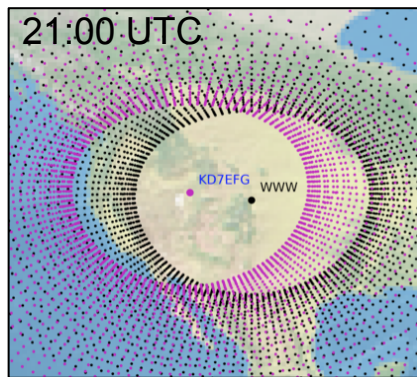


Experience, and informed speculation, suggest hypotheses to test:

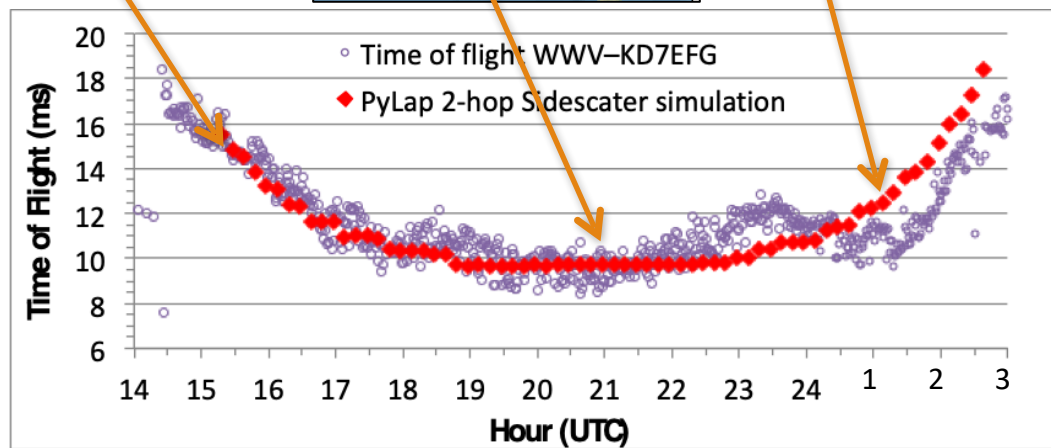
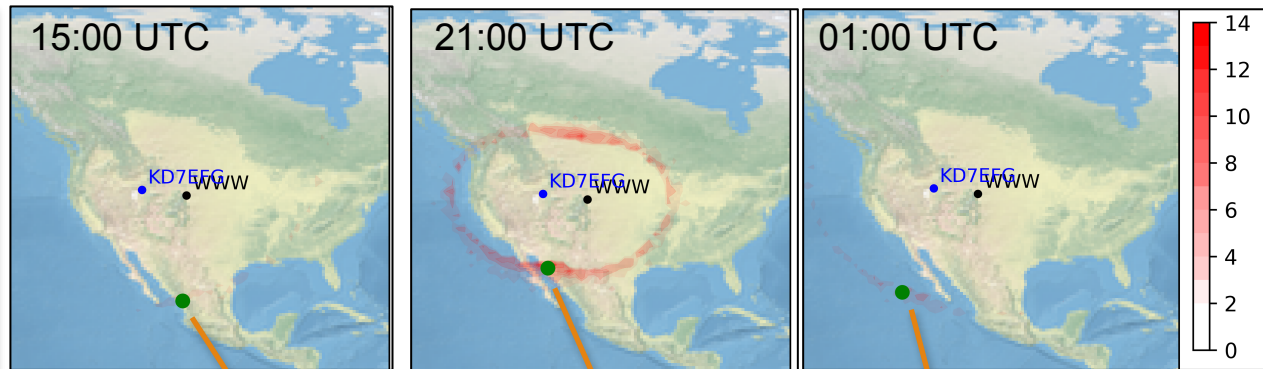
- **A & B & H** : Two-hop sidescatter via the F region
- **C** : One-hop great circle sporadic E
- **D** : Signal processing artefacts
- **E** : Two hop sidescatter via sporadic E
- **F** : Ionospheric forward scatter
- **G** : Half-hop sidescatter

A & B & H : Two-hop sidescatter via the F region

Scripts in the toolbox run 3D PyLap ray tracing over 360° azimuth from transmitter and *pseudo transmitter* at receiver. We map ray landing spots, and find a metric of most overlap: likely sidescatter region.



SS_animate.sh



48 minutes added to
PyLap time

C : One-hop great circle sporadic E (Es)

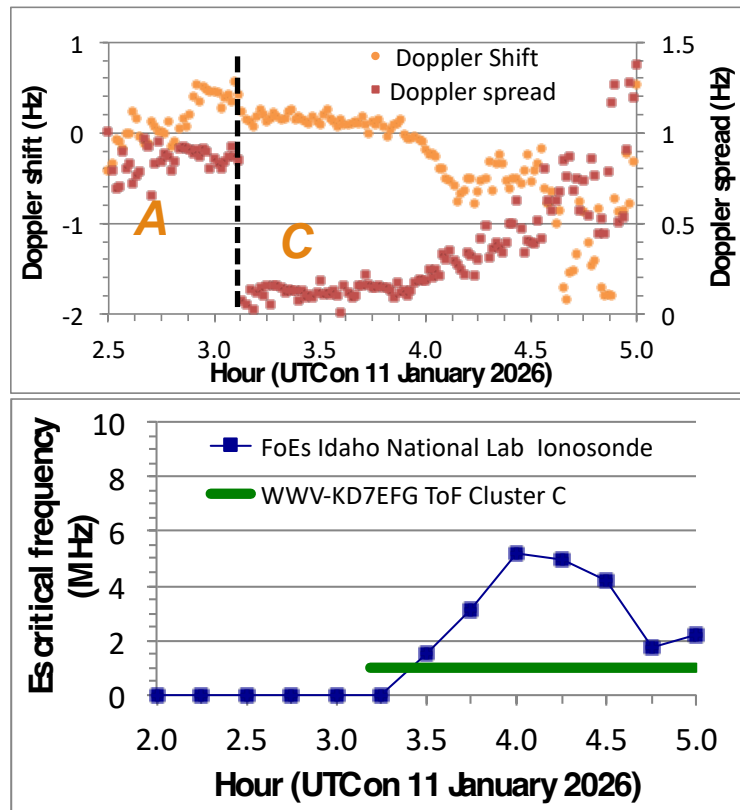
Evidence in support of one-hop great circle E:

- ❑ Mean Time of Flight of 2.19 ms, *but curiously longer than 2.12 ms for daytime one-hop F1.*
- ❑ Narrow Doppler spread 0.13 Hz 03:08 – 04:00, *but followed by steady increase, same mode.*
- ❑ Low Doppler 03:08 – 04:00 at +0.12 Hz, *but curiously not closer to zero, then steady change to negative, then variable for rest of interval C.*

Evidence in support of Es:

- ❑ Ionosonde records at Idaho National Lab, showing existence and rise in Es critical frequency coinciding with our interval C.

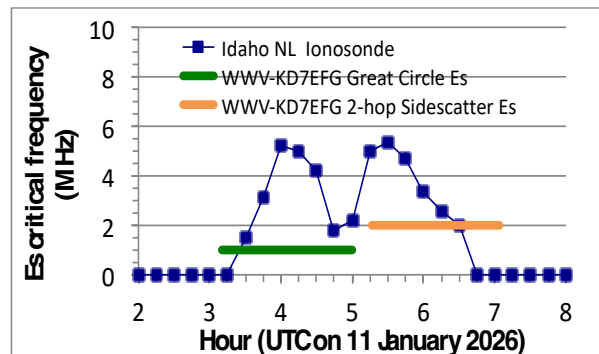
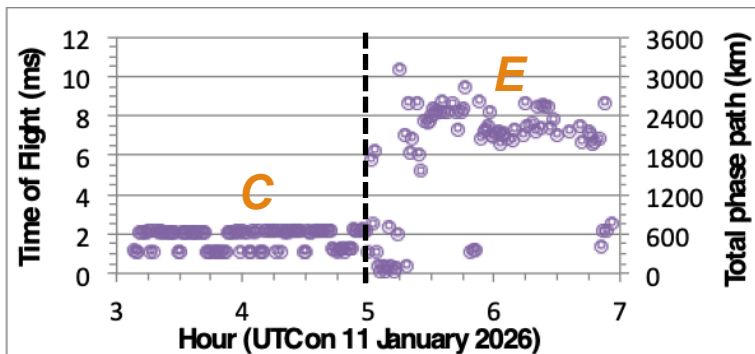
Doppler shift & spread from [grape_acf_doppler_spread.py](#)



E : Two hop sidescatter via sporadic E



Blue circles: locations for *one scenario* where mid-path Es reflections would produce the observations. Distances are ground ranges.



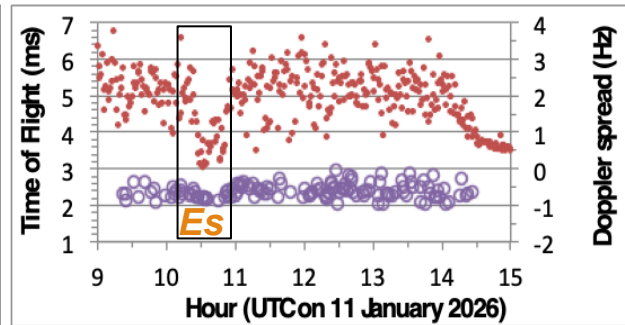
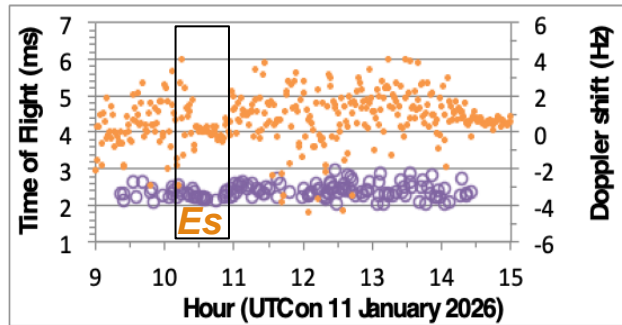
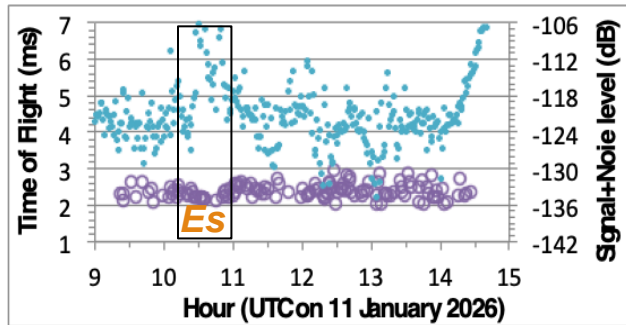
Evidence in support of two-hop sidescatter:

- Time of Flight average 7.52 ms: ~2250 km for 617 km ground path.
- Higher mean Doppler spread at 1.00 Hz vs. 0.13 Hz great circle and lower Signal+Noise level at -117 dB vs. -76 dB great circle.

Evidence for being via sporadic E:

- Es 'cloud' had moved away from WWV-KD7EFG mid path *but* was still present at Idaho ionosonde.

F : Ionospheric forward scatter (Ionoscatter)

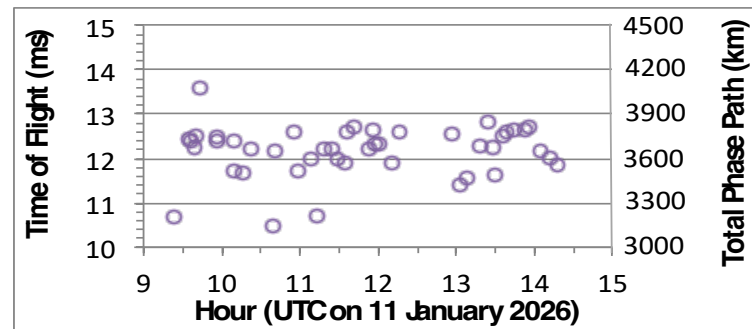
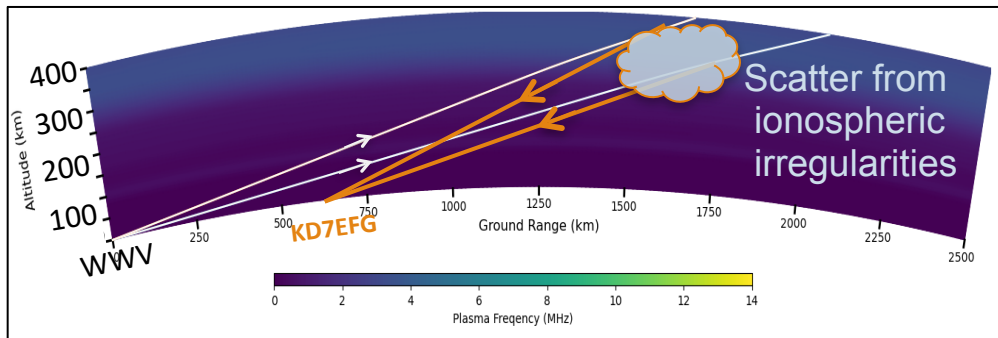


Circumstantial evidence:

- ❑ **One-hop great circle:** 2.38 ms median ToF *but* longer than 2.19 ms ToF for Es
- ❑ **Weak signal:** At or just above noise at rural low-noise site, weaker than two-hop sidescatter on >5000 km round trip.
- ❑ **'Always' present:** Continuous signal present unless stronger signal mode present
- ❑ Autocorrelation Doppler and spread estimates unreliable given very low SNR

<http://hamsci.org>

G : Half-hop backscatter via the F region?



“... from the earliest observations with the first purpose-built mid-latitude radar (Wallops Island), it was clear that the nightside sub-auroral ionosphere often generates backscatter”. Nishitani et al., 2019 link.springer.com/content/pdf/10.1186/s40645-019-0270-5.pdf

If we accept the Time of Flight measurements as valid, they may be half-hop F, as:

- ❑ **Weak signal:** Intermingled with hypothesized one-hop forward Ionoscatter
- ❑ **Median ToF** 12.26 ms *too short* for two-hop F sidescatter (> 16 ms)
too long for two-hop E or Es sidescatter (~ 8 ms)

Concluding remarks

- ❑ Through continuous, on-going, innovation in hardware, software and methods the HamSCI community is producing great data on ionospheric propagation.
- ❑ There *is* community interest in the analysis and interpretation of the data.
- ❑ I've outlined some tools for analysis and synthesis I hope will help and inspire others to get involved and “*Discover Science through Ham Radio*”.



Gwyn spent much of his career on board the Royal Research Ship *Discovery*.